

ASSESSMENT OF RADIO COVERAGE IN INDIAN CITIES USING FDTD

A Project Report

Submitted in partial fulfillment of the requirements for the award of the degree

BACHELOR OF TECHNOLOGY IN ELECTRONICS AND COMMUNICATIONS ENGINEERING

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CERTIFICATE

This is to certify that the thesis entitled, “Assessment of Radio Coverage in Indian cities using FDTD” submitted by Protyush Sahu in partial fulfillments for the requirements for the award of Bachelor of Technology Degree in Electronics & Communications Engineering at National Institute of Technology, Rourkela is an authentic work carried out by him under my supervision and guidance.

To the best of my knowledge, the matter embodied in the thesis has not been submitted to any other University / Institute for the award of any Degree or Diploma.

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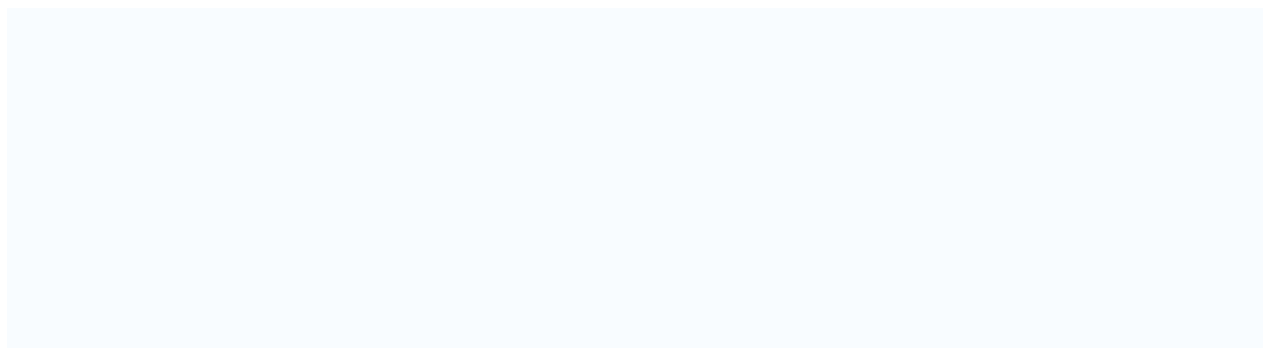
ABSTRACT

Prediction of Radio coverage has seen a massive surge of research in recent years. In this paper we attempt to predict the radio coverage of an extremely complicated urban scenario using a very sophisticated mathematical model called Finite-Difference Time-Domain (FDTD). FDTD technique helps us to model an urban area, with different obstacles, by numerically implementing the Maxwell's equations. This enables us to find the electric and magnetic field strength of different regions. As the simulation is based on basic laws of electromagnetic theory, all the physical phenomena occurring in an urban space are taken into consideration. We use particular electromagnetic parameters such as, electric permittivity, magnetic permeability and electrical conductivity of the materials which form the obstacles. They are aided with the transmission data i.e Transmission power and frequency for deriving the radio power. The simulation is based on a 2 dimensional model of FDTD. This greatly increases our accuracy in complicated scenarios. This also helps us in finding the specific regions that are under very high exposure to radio signals and thereby accessing the risk of health hazards in such regions.

In a last few decades, there has been a surge of research and novelty in prediction of radio power and radio coverage in different regions. The requirement of effective algorithms and proper platforms for simulations has been a prime driving cause. There are a number of models in place for determining radio power in a particular area. But the current tools are based on empirical and semi-empirical models for easier algorithms and short running time. These models have shown effective results in rural and semi-urban scenarios. But they seem to fail in extremely complicated urban scenarios, where all the obstacles must be accurately modelled. In these scenarios, we must take all possible physical phenomena, such as reflection, refraction, diffraction, transmissions and scattering, into consideration.

CHAPTER 1

GENERAL INTRODUCTION



1. General Introduction

A communications system is a collection of individual communications networks, transmission systems, relay stations, tributary stations, and data terminal equipment (DTE) usually capable of interconnection and interoperation to form an integrated whole. The components of a communications system serve a common purpose, are technically compatible, use common procedures, respond to controls, and operate in unison. As such any communications system consists of subsystems which work together to achieve a common link, through achieving its own functionality.

The first wire line telephone system was introduced in the year 1877. Mobile communication systems were set up as early as 1934 and were mostly based on Amplitude Modulation (AM) technique. The increasing demand for newer and better mobile radio communication systems during the World War II and the development of Frequency Modulation (FM) technique by Edwin Armstrong, the mobile radio communication systems began to witness many radical changes. Mobile telephone was introduced in the year 1946. However, during its initial three and a half decades it found very less market penetration owing to high price. Our society has been looking for acquiring mobility in communication since then. Initially the mobile communication was limited between one pair of users on single channel pair. The range of mobility was defined by the transmitter power, type of antenna used and the frequency of operation. With the increase in the number of users, accommodating them within the limited available frequency spectrum became a major problem. To resolve this problem, the concept of cellular communication was evolved. The present day cellular communication uses a basic unit called cell. Each cell consists of small hexagonal area with a base station located at the center of the cell, which communicates with the user. To accommodate multiple users Time Division multiple Access (TDMA), Code Division Multiple Access (CDMA), Frequency Division Multiple Access (FDMA) and their hybrids are used. Cellular telephone systems must accommodate a large number of users over a large geographic area with limited frequency spectrum, i.e., with limited number of channels. A minimum amount of signal strength is needed.

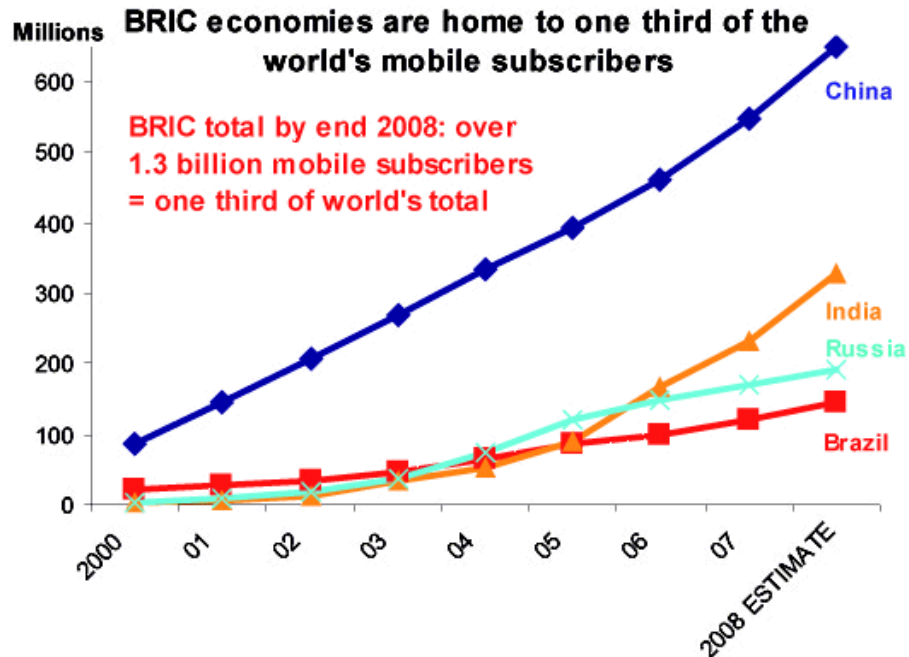


Figure 1. Mobile Subscribers

Based on the type of channels being utilized, mobile radio transmission systems may be classified as the following three categories;

1. **Simplex System:** Simplex systems uses simplex channels hence the communication is unidirectional. The first user can communicate with the second user. However, the second user cannot communicate with the first user. One example of such a system is a pager.
2. **Half Duplex System:** Half duplex radio systems that use half duplex radio channels allow for non-simultaneous bidirectional communication. The first user can communicate with the second user but the second user can communicate to the first user only after the first user has finished his conversation. At a time, the user can only transmit or receive information. A walkie-talkie is an example of a half duplex system which uses 'push to talk' and 'release to listen' type of switches.
3. **Full Duplex System:** Full duplex systems allow two way simultaneous communications. Both the users can communicate to each other simultaneously. Providing two simultaneous but separate channels to both the users can do this.

When a mobile is idle, i.e., it is not experiencing the process of a call, then it searches all the FCCs to determine the one with the highest signal strength. The mobile then monitors this particular FCC. However, when the signal strength falls below a particular threshold that is insufficient for a call to take place, the mobile again searches all the FCCs for the one with the highest signal strength. For a particular country or continent, the control channels will be the same. So all mobiles in that country or continent will search among the same set of control channels. However, when mobile moves to a different country or continent, then the control channels for that particular location will be different and hence the mobile will not work. Due to the increasing complexity of mobile phones, they are often more like mobile computers in their available uses. This has introduced additional difficulties for law enforcement officials in distinguishing one usage from another as drivers use their devices. This is more apparent in those countries which ban both handheld and hands-free usage, rather than those who have banned handheld use only, as officials cannot easily tell which function of the mobile phone is being used simply by looking at the driver. This can lead to drivers being stopped for using their device illegally on a phone call when, in fact, they were using the device for a legal purpose such as the phone's incorporated controls for car stereo.

CHAPTER 2

RF PREDICTION

RAY TRACING

EVOLVING METHODOLOGY

MODERN TECHNIQUES

2. RF PREDICTION

2.1 RAY TRACING

Ray tracing is a method to produce realistic images; it determines visible surfaces in an image at the pixel level. Unlike the z-buffer and BSP tree, ray tracing operates pixel-by-pixel rather than primitive-by-primitive. This tends to make ray tracing relatively slow for scenes with large objects in screen space. However, it has a variety of nice features which often make it the right choice for batch rendering and even for some interactive applications. Ray tracing's primary benefit is that it is relatively straightforward to compute shadows and reflections. In addition, ray tracing is well suited to "walkthroughs" of extremely large models due to advanced ray tracing's low asymptotic time complexity which makes up for the required preprocessing of the model. In an interactive 3D program implemented in a conventional z-buffer environment, it is often useful to be able to select an object using a mouse. The mouse is clicked in pixel (i, j) and the "picked" object is whatever object is "seen" through that pixel. If the rasterization process includes an object identification buffer, this is just a matter of looking up the value in pixel (i, j) of that buffer. However, if that buffer is not available, we can solve the problem of which object is visible via brute force geometrical computation using a "ray intersection test." In this way, ray tracing is useful also to programmers who use only standard graphics APIs.

The simplest use of ray tracing is to produce images similar to those produced by the z-buffer and BSP-tree algorithms. Fundamentally, those methods make sure the appropriate object is "seen" through each pixel, and that the pixel color is shaded based on that object's material properties, the surface normal seen through that pixel, and the light geometry. The intersection points occur when points on the ray satisfy the implicit equation. The key class hierarchy in a ray tracer are the geometric objects that make up the model. These should be subclasses of some geometric object class, and they should support a hit function. To avoid confusion from use of the word "object," surface is the class name often used. With such a class, you can create a ray tracer that has a general interface that assumes little about modeling primitives and debug it using only spheres. An important point is that anything that can be "hit" by a ray should be part of this class hierarchy, e.g., even a collection of surfaces should be considered a subclass of the

surface class. This includes efficiency structures, such as bounding volume hierarchies; they can be hit by a ray, so they are in the class. Once you have a basic ray tracing program, shadows can be added very easily. Recall from Chapter 9 that light comes from some direction l . If we imagine ourselves at a point p on a surface being shaded, the point is in shadow if we “look” in direction l and see an object. If there are no objects, then the light is not blocked. The First generation of wireless telecommunication technology used analog transmission techniques which were basically used for transmitting voice signals. 1G or first generation of wireless telecommunication technology also consist of various standards among which most popular were Advance Mobile Phone Service (AMPS), Nordic Mobile Telephone (NMT), Total Access Communication System (TACS). All of the standards in 1G use frequency modulation techniques for voice signals and all the handover decisions were taken at the Base Stations (BS). The spectrum within cell was divided into number of channels and every call is allotted a dedicated pair of channels. Data transmission between the wire part of connection and PSTN (Packet Switched Telephone Network) was done using packet-switched network.

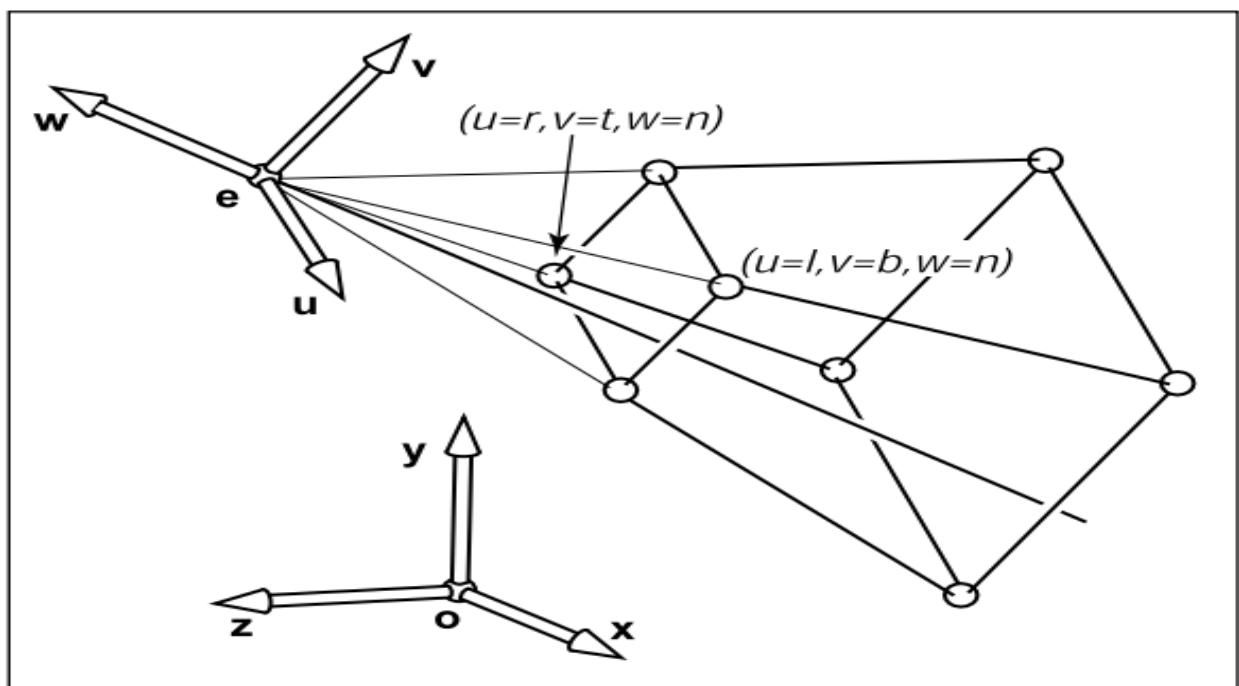


Figure 2 Ray Tracing

2.2 EVOLVING METHODOLOGY

The GSM standard, introduced by Groupe Special Mobile, was aimed at designing a uniform pan-European mobile system. It was the first fully digital system utilizing the 900 MHz frequency band. The initial GSM had 200 KHz radio channels, 8 full-rate or 16 half-rate TDMA channels per carrier, encryption of speech, low speed data services and support for SMS for which it gained quick popularity. The IS-95 standard, also popularly known as CDMAOne, uses 64 orthogonally coded users and code words are transmitted simultaneously on each of 1.25 MHz channels. Certain services that have been standardized as a part of IS-95 standard are: short messaging service, slotted paging, over-the-air activation (meaning the mobile can be activated by the service provider without any third party intervention), enhanced mobile station identities etc.

In an effort to retrofit the 2G standards for compatibility with increased throughput rates to support modern Internet application, the new data centric standards were developed to be overlaid on 2G standards and this is known as 2.5G standard. Here, the main up gradation techniques are:

- Supporting higher data rate transmission for web browsing
- Supporting e-mail traffic
- Enabling location-based mobile service

2.5G networks also brought into the market some popular application, a few of which are:

Wireless Application Protocol (WAP), General Packet Radio Service (GPRS), High Speed Circuit Switched Data (HSCSD), Enhanced Data rates for GSM Evolution (EDGE) etc. EDGE is standardized by 3GPP as part of the GSM family and it is an upgrade that provides a potential three-fold increase in capacity of GSM/GPRS networks. The 2G digital service provided very useful feature like; expended capacity and unique service such as caller ID, call forwarding, and short messaging.

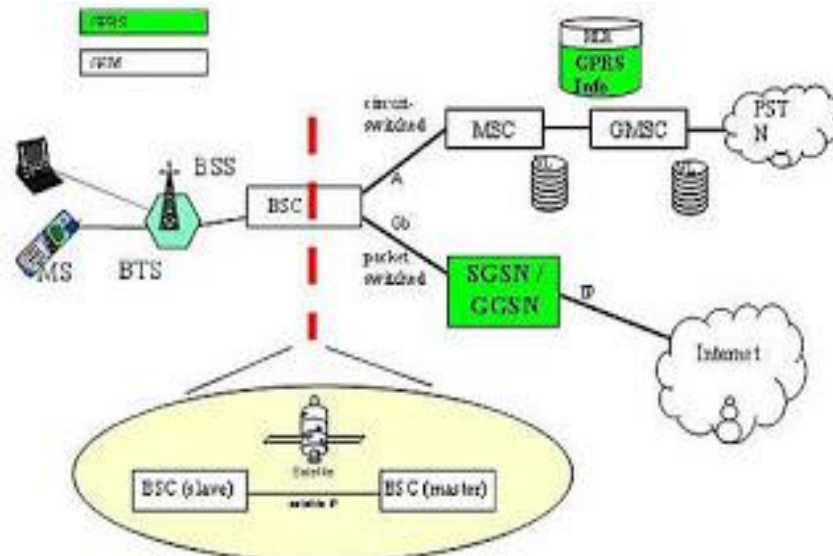


Figure 3 Communication Network

Many operators also provide the Internet service for second-generation mobile communication networks. They became extremely popular in the developing countries such as, India, China, Brazil, Russia and South Africa. But in many a cases the speed difference between second-generation and third-generation mobile system doesn't seem to be too big. The reason is the limited bandwidth. Bandwidth does play a big role in influencing the data rate of the wireless communication system. The relation between the data rate and bandwidth is a direct result of the Shannon limit. Because of such uncertainty and the increasing influence of the higher generation wireless systems, many of the mobile service providers and operators have decided to shut down the second-generation mobile technology. The advent of this technology created the so-called mobile Internet revolution. Various carriers such as AT&T have made announcements that 2G GSM technology in the United States is in the process of being shut down so that carriers can reclaim those radio bands and re-purpose them for future technology needs. The shut down will be complete by the end of 2016. All 2G GSM devices will lose service at some point between now and the end of 2016. This shut down is having a notable impact on the electronic security industry where many 2G GSM radios are in use for alarm signal communication to Central Station dispatch centers. 2G GSM radios must be replaced by newer generation radios to avoid service outages.

2.3 MODERN TECHNIQUES:

The far-reaching demand for wireless communication technologies is ever increasing in all the human life activities and this has boosted the development of Wireless Local Area Networks (WLANs). Among the WLAN standards, the IEEE 802.11 is the most popular one. A Schema of the IEEE 802.11 standard is represented in figure 1. The IEEE 802.11 standard defines both the physical (PHY) and medium access control (MAC) layers of the network. The basic network building block defined by the standard is the infrastructure Basic Service Set (BSS) which is composed of a single Access Point (AP) connected to a wired backbone network providing wireless connectivity to a bunch of mobile users. Thus, Aps, normally routers, are base stations for the wireless network. Thus, the development of efficient transmission, operation and management WLAN technologies requires a greater precision on the estimations of the system signal coverage, which is given by propagation path loss models. This is usually done in order to obtain “total coverage” with which the operator attempts to assure the quality of service. Propagation models to help network designer estimate the signal coverage and pathloss for a given deployment plan, as well as perform automated placement of access points. For this reason a precise and flexible prediction methodologies of signal coverage with easy implementation is needed. Wireless communication systems are used everywhere, both in indoor and outdoor environments. In these environments, customers demand a good coverage and quality of service. Operator deployment provisions must classically guarantee coverage, with certain quality requirements, of a minimum percent of the geographical area and population (e.g., 90-95 % of the geographical area and population covered). Today the challenge is how to accurately predict the propagation signal coverage and path loss at the cellular frequency of 2.4 GHz in outdoor terrain. There are several empirical propagation models which can precisely calculate up to 2 GHz. But beyond 2 GHz, there are few reliable models which can be referred for the WLAN context. So far, WLAN propagation studies are more tuned to the indoor communications; however, WLAN outdoor networks may also play a role in the wireless communications. Even more so, there had been no upkeep of path loss modeling for the 2.4 GHz frequency, which holds a dominant role in indoor wireless networks (802.11b/g/n) and will continue to be of importance as next-generation networks come into the forefront. Also, the possibility of using WLAN communications for long ranges can therefore be an important feature to add to the WLAN list of

exciting potentials. The Log-distance model is an empirical approach for deriving radio propagation models and it is based on fitting curves or analytical expressions that recreate a set of measured data. Adopting this approach has the advantage of taking into account all the known and unknown phenomena in channel modeling. In this model, power decreases logarithmically with distance. The average loss for a given distance is expressed using a Path Loss Exponent, n . The Log-distance propagation model is the path loss model that will be used in this research. There also exist many studies that use a variation of the Log-distance Path Loss model.

The peak bit rate is further improved by smart antenna arrays for multiple-input multiple-output (MIMO) communications. This upgrade path makes it more cost effective for vendors to offer LTE and then upgrade to LTE Advanced which is similar to the upgrade from WCDMA to HSPA. LTE and LTE Advanced will also make use of additional spectrums and multiplexing to allow it to achieve higher data speeds. Coordinated Multi-point Transmission will also allow more system capacity to help handle the enhanced data speeds. Release 10 of LTE is expected to achieve the IMT Advanced speeds. Release 8 currently supports up to 300 Mbit/s of download speeds which is still short of the IMT-Advanced standards. TD-LTE is not the first 4G wireless mobile broadband network data standard, but it is China's 4G standard that was amended and published by China's largest telecom operator - China Mobile. After a series of field trials, is expected to be released into the commercial phase in the next two years. Ulf Ewaldsson, Ericsson's vice president said: "the Chinese Ministry of Industry and China Mobile in the fourth quarter of this year will hold a large-scale field test, by then, Ericsson will help the hand." But viewing from the current development trend, whether this standard advocated by China Mobile will be widely recognized by the international market is still debatable. Both transmit/receive diversity and transmit spatial multiplexing are categorized into the space-time coding techniques, which does not necessarily require the channel knowledge at the transmitter. The other category is closed-loop multiple antenna technologies, which require channel knowledge at the transmitter.

CHAPTER 3

FINITE DIFFERENCE TIME DOMAIN TECHNIQUE

TRANSMISSION PARAMETERS

POWER DELAY PROFILE

ELECTROMAGNETIC EQUATIONS

3. FINITE DIFFERENCE TIME DOMAIN

3.1 TRANSMISSION PARAMETERS

There are various kinds of transmission parameters that come into play when it comes to analyzing the electromagnetic field. The very first thing that plays a crucial role in our simulations is the transmitter position. Along with it the power and the antenna gain make a profound effect on the radiated power. This is coupled with power delay profile and bandwidth to give the theoretical analysis of electromagnetic power.

1. Transmitter Location: The transmitter location gives us the radius of influence of the particular transmitter antenna corresponding to the give wavelength and bandwidth. It helps us to analyze the size of cells and the number of users as well as capacity of the cells. Most of the cells used in the Indian urban cities have a honeycomb hexagonal structure and thereby have a directional antenna that provides with angular power in a particular cell. The antenna may be enclosed inside the case or attached to the outside of the transmitter, as in portable devices such as cell phones, walkie-talkies, and garage door openers. In more powerful transmitters, the antenna may be located on top of a building or on a separate tower, and connected to the transmitter by a feed line, that is a transmission line. The operator of the transmitter usually must hold a government license, such as a general radiotelephone operator license, which is obtained by passing a test demonstrating adequate technical and legal knowledge of safe radio operation. An exception is made allowing the unlicensed use of low-power short-range transmitters in devices such as wireless microphones, walkie-talkies, Wifi and Bluetooth devices, garage door openers, and baby monitors. In the US, these fall under Part 15 FCC regulations. Although they can be operated without a license, these devices still generally must be type-approved before sale.
2. Frequency and Bandwidth: Frequency of the radiated electromagnetic signal does play a crucial role in determining the values of electric and magnetic field in the Yee cells and thereby provide us the real time operation of the finite difference time domain method.

The word bandwidth applies to signals as described above, but it could also apply to *systems*, for example filters or communication channels. To say that a system has a certain bandwidth means that the system can process signals of that bandwidth, or that the system reduces the bandwidth of a white noise input to that bandwidth. In communication systems, in calculations of the Shannon–Hartley channel capacity, bandwidth refers to the 3dB-bandwidth. In calculations of the maximum symbol rate, the Nyquist sampling rate, and maximum bit rate according to the Hartley formula, the bandwidth refers to the frequency range within which the gain is non-zero, or the gain in dB is below a very large value.

3. Antenna's power gain or simply gain refers to the key performance figure which combines the antenna's directivity and electrical efficiency. Directive gain or directivity is a different measure which does *not* take an antenna's electrical efficiency into account. This term is sometimes more relevant in the case of a receiving antenna where one is concerned mainly with the ability of an antenna to receive signals from one direction while rejecting interfering signals coming from a different direction. Power gain (or simply gain) is a unit less measure that combines an antenna's efficiency $E_{antenna}$ and directivity D :

$$G = E_a D$$

If we consider the elevation and the azimuth of the antenna direction, the our equation becomes:

$$G(\theta, \phi) = E_a D(\theta, \phi)$$

The power gain is the ratio of radiated power in a given direction relative to that of an isotropic radiator which is radiating the total amount of electrical power received by the antenna in question. This is different from the directive gain which ignores any reduction in efficiency. If a certain portion of the electrical power received from the transmitter is actually radiated by the antenna (i.e. less than 100% efficiency), then the directive gain compares the power radiated in a given direction to that reduced power (instead of the total power received).

On the other hand, the power gain takes into account the poorer efficiency by comparing the radiated power in a given direction to the actual power that the antenna receives from the transmitter.

The radiation intensity U expresses the power radiated per solid angle. In terms of U the power gain in a specified direction can be calculated:

$$G = U/(P_{in}/4\pi)$$

where G = Power Gain of the antenna

P_{in} = net electrical power entering the antenna terminals

The net electrical power entering the antenna terminals is given by:

$$P_{in} = V^2 \cdot \text{Re}\left(\frac{1}{Z_{in}}\right)$$

V = Root mean square voltage at the antenna terminals.

Z_{in} = feed point impedance

However in most of the cases the antenna gain is expressed in terms of the decibels. All the parameters are combined to give us the value of the power that comes out from the transmitting antenna. From the given values of all these parameters we can calculate the value of the electromagnetic field of the radiation. The relationship between the electromagnetic field and the power of the electromagnetic radiation is given by the Poynting theorem. We make use of the this equation to enable us to calculate the values of electric and magnetic field, in the given polarization direction (to take into account the directivity of the transmitting antenna), in different Yee cells. Upon finding the initial values of the electromagnetic fields in the Yee cell, we simulate the finite difference time domain method to the given urban scenario and thereby find the value of the time varying electric and magnetic field in the particular area. This enables us to find the real time variation of the electromagnetic field in the corresponding. We then go ahead to calculate the value of the electromagnetic power using the pointing theorem.

3.2 POWER DELAY PROFILE

There are two basic ways of transmitting an electro-magnetic (EM) signal, through a guided medium or through an unguided medium. Guided mediums such as coaxial cables and fiber optic cables, are far less hostile toward the information carrying EM signal than the wireless or the unguided medium. It presents challenges and conditions which are unique for this kind of transmissions. A signal, as it travels through the wireless channel, undergoes many kinds of propagation effects such as reflection, diffraction and scattering, due to the presence of buildings, mountains and other such obstructions.

3.2.1 FREE SPACE PROPAGATION MODEL

Although EM signals when traveling through wireless channels experience fading effects due to various effects, but in some cases the transmission is with a direct line of sight such as in satellite communication. Free space model predicts that the received power decays as negative square root of the distance. Friis free space equation is given by:

$$P_r = \frac{P_t G_t G_r \lambda^2}{16 \pi^2 d^2 L}$$

where P_t is the transmitted power

$P_r(d)$ is the received power

G_t is the transmitter antenna gain

G_r is the receiver antenna gain

d is the Tx-Rx separation

L is the system loss factor

3.2.2 BASIC METHOD OF PROPAGATION

The most important parameter, predicted by propagation models based on different phenomena, is the received power. The physics of the above phenomena may also be used to describe small scale fading and multipath propagation. The following subsections give an outline of these phenomena. Reflection occurs when an electromagnetic wave falls on an object, which has very large dimensions as compared to the wavelength of the propagating wave. For example, such objects can be the earth, buildings and walls. If the medium on which the electromagnetic wave is incident is a dielectric, some energy is reflected back and some energy is transmitted. If the medium is a perfect conductor, all energy is reflected back to the first medium. The amount of energy that is reflected back depends on the polarization of the electromagnetic wave. The actual received power at the receiver is somewhat stronger than claimed by the models of reflection and diffraction. The cause is that the trees, buildings and lamp- posts scatter energy in all directions.

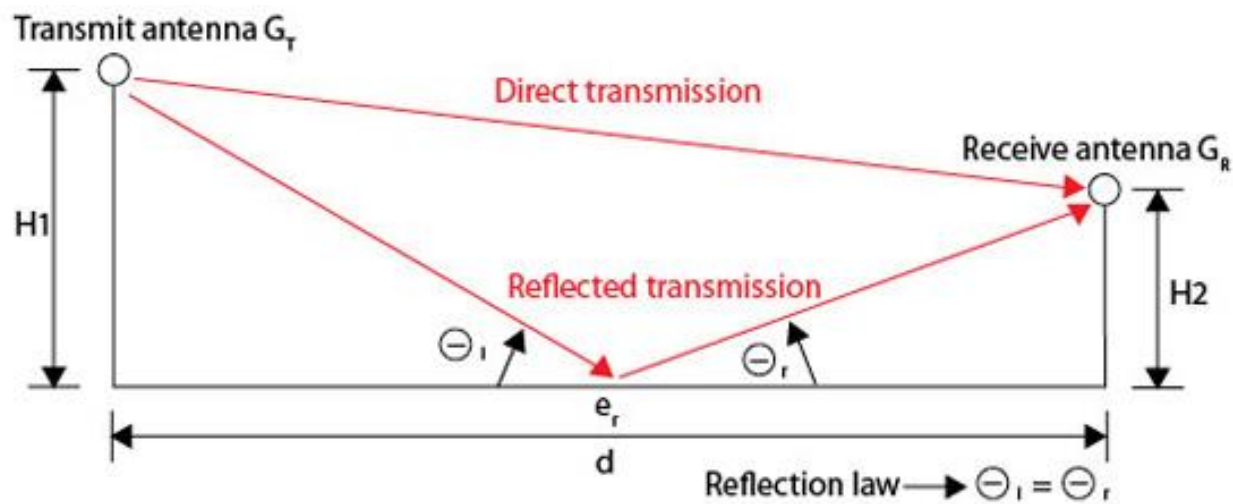


Figure 4 Multipath Propagation

Multipath phenomena is sometimes exploited by the receiver to increase the diversity of the channel. Increasing the diversity of the channel helps us to increase the effective signal to noise ratio of the respective channel.

3.3 ELECTROMAGNETIC EQUATIONS

In a last few decades, there has been a surge of research and novelty in prediction of radio power and radio coverage in different regions. The requirement of effective algorithms and proper platforms for simulations has been a prime driving cause. There are a number of models in place for determining radio power in a particular area. But the current tools are based on empirical and semi-empirical models for easier algorithms and short running time. These models have shown effective results in rural and semi-urban scenarios. But they seem to fail in extremely complicated urban scenarios, where all the obstacles must be accurately modeled. In these scenarios, we must take all possible physical phenomena, such as reflection, refraction, diffraction, transmissions and scattering, into consideration. Ray tracing models can be used in such cases except in an extremely complicated environment where there are multiple reflections and scattering of the objects. A model, which has recently come to light as an effective model in extremely complicated urban scenarios, is Finite Difference Time Domain (FDTD) method, which is heavily used in calculating the power distribution in an urban scenario. This method is based on basic laws of electromagnetism, which helps us to gain higher penetration into the simulation of the urban models. This technique is exclusively effective in urban scenarios with multiple buildings, which are closely spaced.

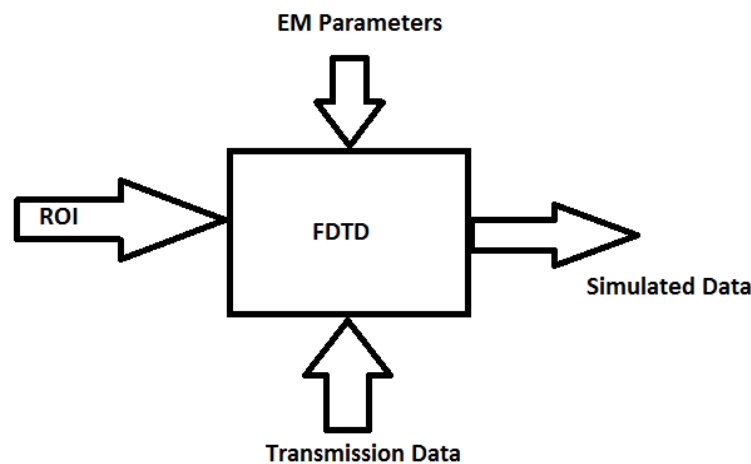


Figure 5 Schematic of FDTD

One of the biggest advantages of FDTD is that, it takes into account the basic electric and magnetic field component of the radiation in a modeled environment, as it is based on Maxwell's equations for calculating the strength of the fields. It can also imbibe other obstacles typically

found in an urban space like trees and vegetation. The strength of the fields helps us in calculating the power distribution in an area. The algorithms can be extremely complicated for an urban scenario but they provide the required accuracy in predicting radio coverage in an area.

This technique is based on the numerical simulation of electric and magnetic field components of radio waves. We use a two dimensional FDTD method to simulate workspaces. We first choose a particular urban scenario, called the Region of Interest (ROI). The satellite images of the ROIs provide us the 2D workspace to model our simulation. We start by dividing the ROI into extremely small cells called Yee cells. The shape and size of Yee cells can vary depending on the size of the ROI and various complications involved. For modeling our environment, we took these Yee cells to be square in shape and the side of the square being 2 meters. The accuracy of the results is strongly dependent on the size of Yee cells. Smaller Yee cells give us an accurate result. The next step involves making the Maxwell's equations numerical. For predicting the propagation of electromagnetic waves with vertical polarization in a 2D simulator, we can restrict the formulation of Maxwell's equation to TMz mode (electric field polarized in vertical direction).

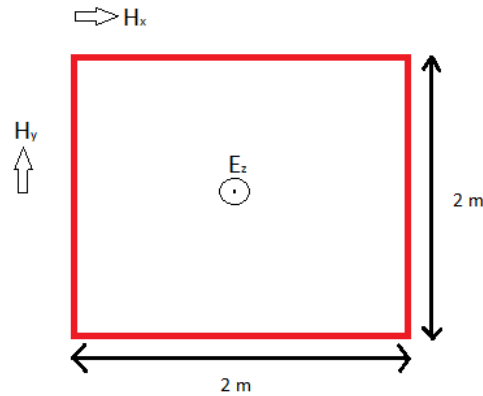


Figure 6 Yee Cell

Based on the sizes of the chosen ROI, numbers of Yee cells in our model were between 2 million to 5 million. Electric and Magnetic field components can be updated in a spatial grid sampled model. Based on it, we can derive the equations of FDTD for TMz mode of Maxwell's equations.

$$H_x|_{i-\frac{1}{2},j+1}^{n+1} = D_a\left(i-\frac{1}{2},j+1\right)H_x|_{i,j+\frac{1}{2}}^n + D_b\left(i-\frac{1}{2},j+1\right) [E_z|_{i-\frac{1}{2},j+\frac{1}{2}}^{n+\frac{1}{2}} - E_z|_{i-\frac{1}{2},j+\frac{3}{2}}^{n+\frac{1}{2}}] \quad (1)$$

$$H_y|_{i,j+\frac{1}{2}}^{n+1} = D_a\left(i,j+\frac{1}{2}\right)H_y|_{i,j+\frac{1}{2}}^n + D_b\left(i,j+\frac{1}{2}\right) [E_z|_{i+\frac{1}{2},j+\frac{1}{2}}^{n+\frac{1}{2}} - E_z|_{i-\frac{1}{2},j+\frac{1}{2}}^{n+\frac{1}{2}}] \quad (2)$$

$$E_z|_{i-\frac{1}{2},j+\frac{1}{2}}^{n+\frac{1}{2}} = C_a\left(i-\frac{1}{2},j+\frac{1}{2}\right)E_z|_{i-\frac{1}{2},j+\frac{1}{2}}^{n-\frac{1}{2}} + C_b\left(i-\frac{1}{2},j+\frac{1}{2}\right) [H_y|_{i,j+\frac{1}{2}}^n - H_y|_{i-1,j+\frac{1}{2}}^n] \quad (3)$$

Here H_x and H_y are the magnetic field components in the x and y direction of the Yee cell respectively.

E_z is the component of the electric field in z direction (coming out of the plane). i and j refer to the indices of the corresponding Yee cell in the 2D model. D_a, D_b, C_a, C_b are the updating coefficients. They are given by:

$$C_a(i,j) = \frac{(1-\frac{\sigma_{i,j}\Delta t}{2\varepsilon_{i,j}})}{(1+\frac{\sigma_{i,j}\Delta t}{2\varepsilon_{i,j}})} \quad (4)$$

$$C_b(i,j) = \frac{\frac{\Delta t}{2\varepsilon_{i,j}\Delta x}}{(1+\frac{\sigma_{i,j}\Delta t}{2\varepsilon_{i,j}})} \quad (5)$$

$$D_a(i,j) = \frac{(1-\frac{\sigma_{i,j}^*\Delta t}{2\mu_{i,j}})}{(1+\frac{\sigma_{i,j}^*\Delta t}{2\mu_{i,j}})} \quad (6)$$

$$D_b(i,j) = \frac{\frac{\Delta t}{2\mu_{i,j}\Delta x}}{(1+\frac{\sigma_{i,j}^*\Delta t}{2\mu_{i,j}})} \quad (7)$$

Here $\sigma(i,j)$, $\mu(i,j)$ and $\varepsilon(i,j)$ refers to the electrical conductivity, magnetic permeability and electric permittivity of the materials in the corresponding Yee cell (i,j) . Δx is the side length of the Yee cell and Δt is the corresponding time interval in the model. Using these equations, we can simulate a 2D urban scenario to find the real time radio coverage in the area.

CHAPTER 4

MEASUREMENTS AND SIMULATIONS

URBAN SIMULATION

RURAL SIMULATION

INDOOR PROPAGATION

4. MEASUREMENTS AND SIMULATIONS

4.1 URBAN SIMULATION

Our simulation model involved 4 different work areas in different cities. These field areas were chosen keeping in mind the diversity of different obstacles and their relative parameters. Three of these locations were chosen in the city of Rourkela (Odisha). They were chosen so that we get an even distribution of different physical parameters affecting the radio coverage. These locations involved both urban and slightly semi-urban scenarios. One location was chosen in the city of Cuttack, which was mostly urban. Two other locations were chosen in the city of Bhubaneswar which were extremely complicated urban scenarios. The simulation included modelling different obstacles. Most of the materials fell in two categories: Brick Mortar and Vegetation. This basically included finding different transmission stations in the ROI, transmitted power and the transmission frequency of each of these stations. Using the information of the transmitted power, we could find the initial Electric and Magnetic field strengths in all the Yee cells. Aided with the electromagnetic parameters of the obstacle materials, we simulated these 4 regions to predict the radio coverage in the regions.

ROI: Rudimentary communication networks Koel Nagar (Rourkela)

OPERATOR	TRANSMITTING POWER(in dB)	TRANSMITTING FREQUENCY(in MHz)
BSNL 2G	20	935
BSNL 3G	12	2100
VODAFONE	18	910

The information for these base stations were collected using a manual mobile handset that could provide us the information of the received power and the receiving frequency at these locations.

Algorithm for Electric and Magnetic field update:

1. Load ROI;
2. Load material parameters;
3. Load antenna gain;
4. Load frequency;
5. Load bandwidth;
6. Load initial power;
7. Define Yee cell parameters;
8. For n = 1: Total time
9. For i=1:N
10. For j=1:N
11. Update $\rightarrow H_x|_{i,j}^n$;
12. Update $\rightarrow H_y|_{i,j}^n$;
13. Update $\rightarrow E_z|_{i,j}^n$;
14. End
15. End
16. End

Using the data from the transmission stations i.e Power and Frequency of radio signals, we can simulate the 2D environment of complicated urban scenarios. This helps us to compute the radio coverage in different places in the ROI. The simulation is based on a 2 dimensional model of FDTD. This greatly increases our accuracy in complicated scenarios. This also helps us in finding the specific regions that are under very high exposure to radio signals and thereby accessing the risk of health hazards in such regions. Finite difference schemes for time-dependent PDEs have been employed for many years in computational fluid dynamics problems, including the idea of using centered finite difference operators on staggered grids in space and time to achieve second-order accuracy.

The novelty of Kane Yee's FDTD scheme, presented in his seminal 1966 paper, was to apply centered finite difference operators on staggered grids in space and time for each electric and magnetic vector field component in Maxwell's curl equations. The descriptor "Finite-difference time-domain" and its corresponding "FDTD" acronym were originated by Allen Taflove in 1980. Since about 1990, FDTD techniques have emerged as primary means to computationally model many scientific and engineering problems dealing with electromagnetic wave interactions with material structures.

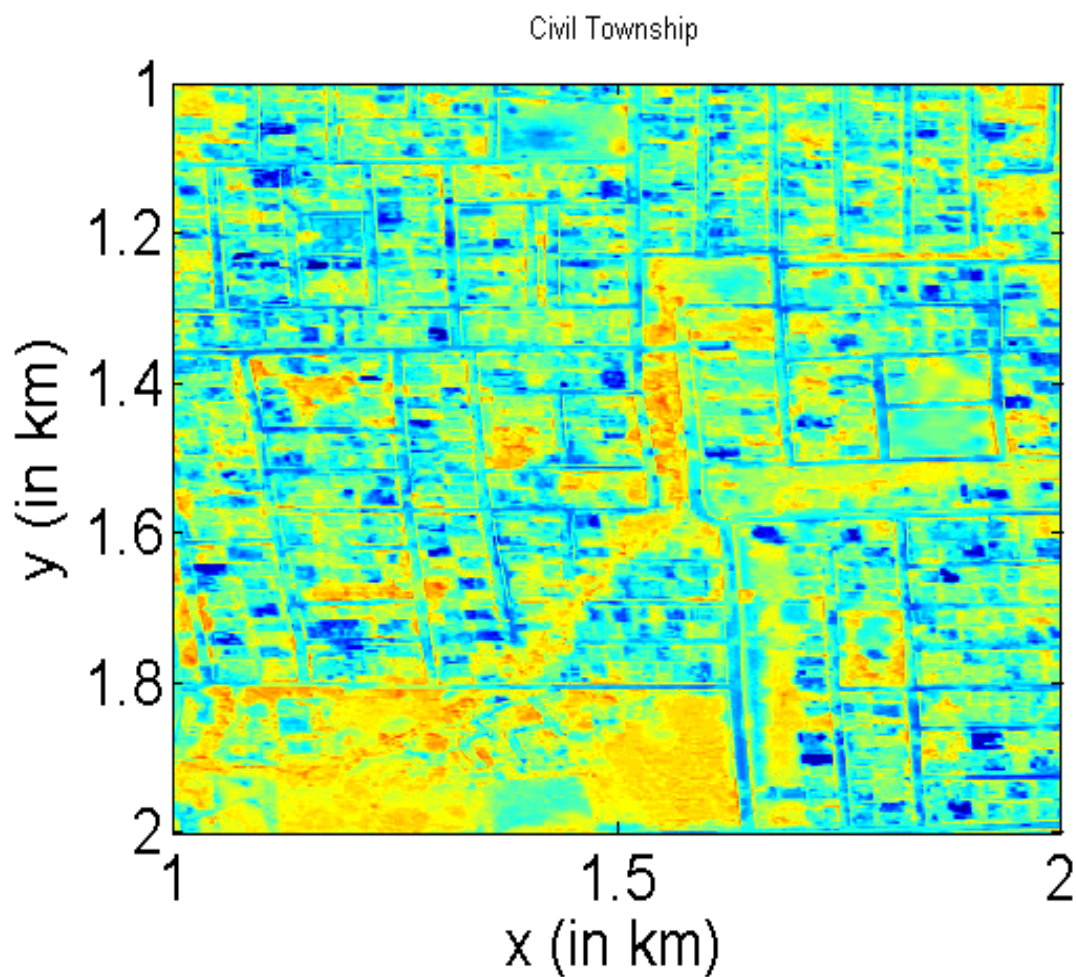


Figure 7 Simulation 1

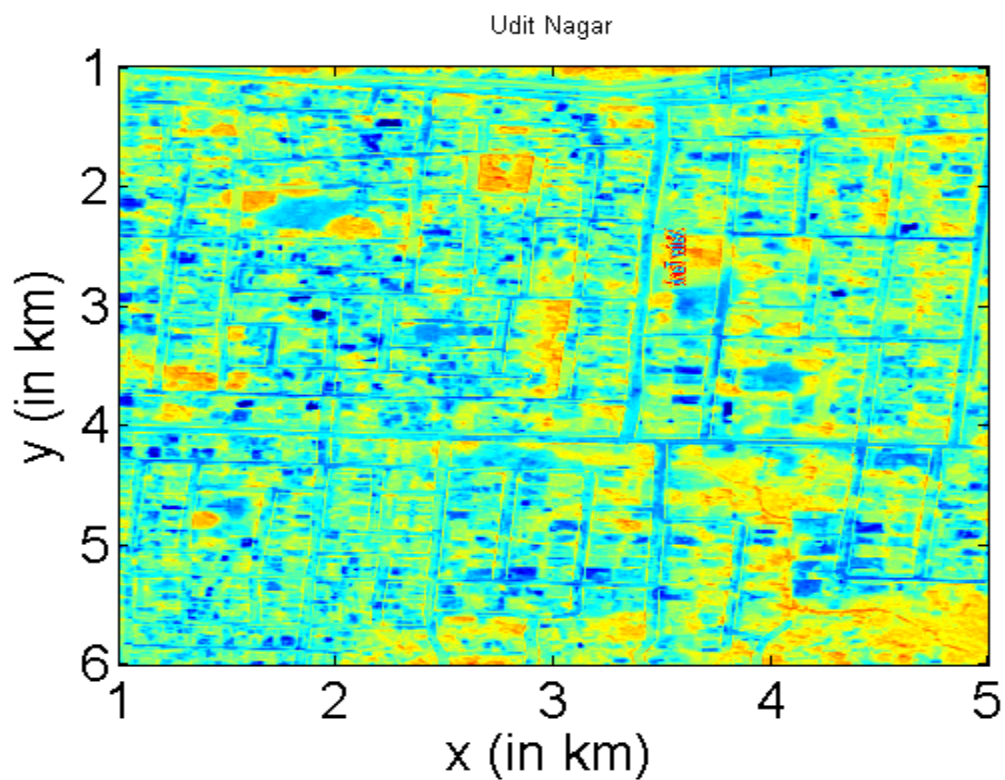


Figure 8 Simulation 2

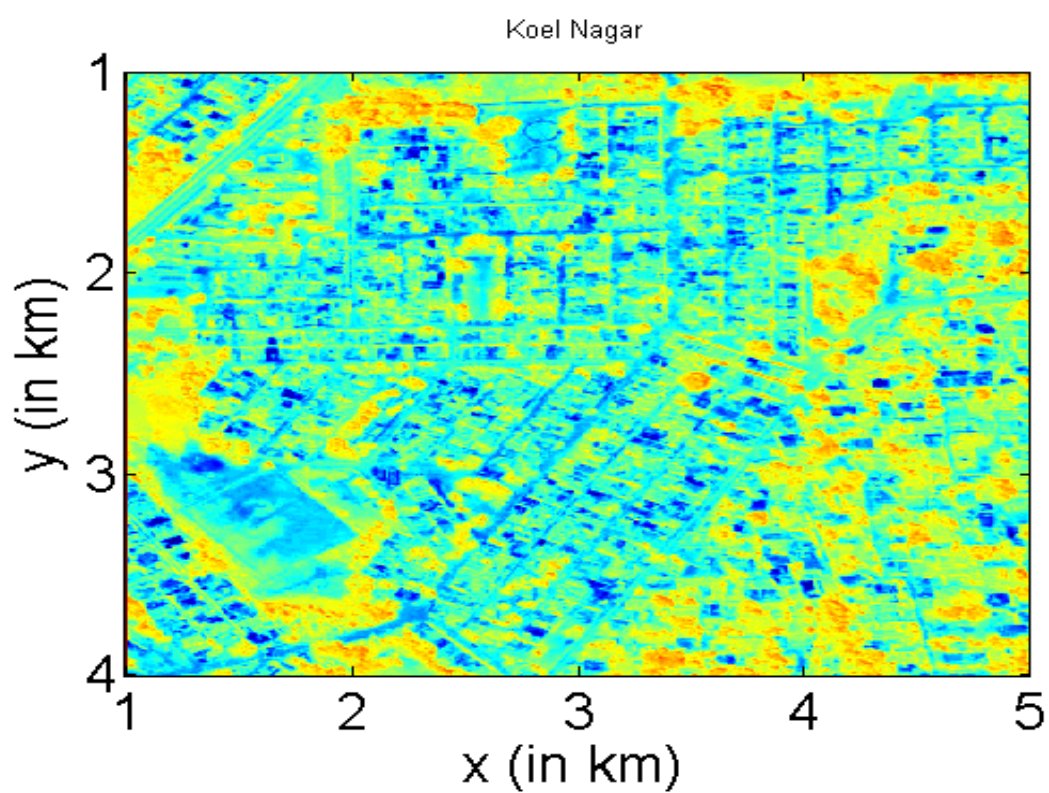


Figure 9 Simulation 3

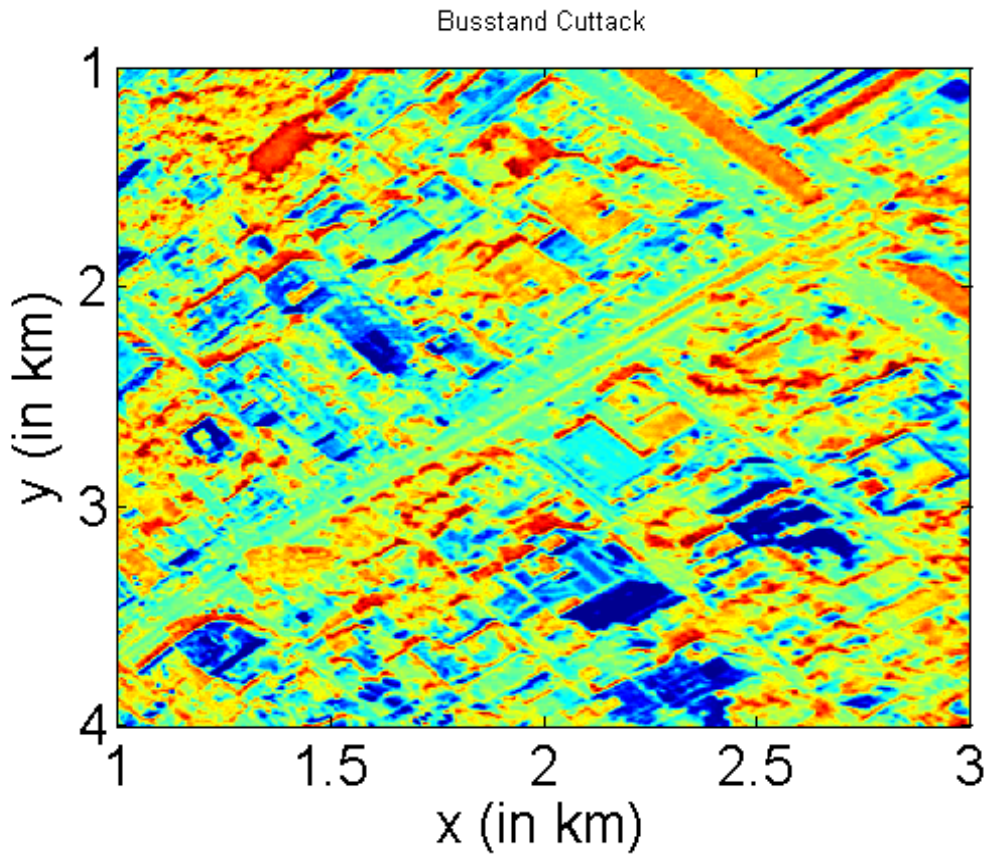


Figure 10 Simulation 4

As it can be seen from the simulation that the power distribution is corresponding to the theoretically limited values. The regions of red are the places of high electromagnetic power and the places of blue are the regions of low electromagnetic power. This corresponds with the fact that blue regions are situated close to the walls which are made of brick and mortar and the regions of high electromagnetic power (red) are the vegetation areas. The results have shown that a design perspective is necessary in predicting a radio power distribution in an area. We introduced an efficient simulation technique and model for predicting the radio coverage in extremely complicated urban scenarios. Interaction of EM waves with materials having different electrical properties than the material through which the wave is traveling leads to transmitting of energy through the medium and reflection of energy back in the medium of propagation. The amount of energy reflected to the amount of energy incident is represented by Fresnel reflection coefficient Γ , which depends upon the wave polarization, angle of incidence and frequency of the wave.

4.2 RURAL SIMULATION:

In this section we will discuss the simulation of rural areas using the novel fdtd technique. Seldom in communication systems we encounter channels with only LOS paths and hence the Friis formula is not a very accurate description of the communication link. A two-ray model, which consists of two overlapping waves at the receiver, one direct path and one reflected wave from the ground gives a more accurate description. A simple addition of a single reflected wave shows that power varies inversely with the forth power of the distance between the Tx and the Rx. This is deduced via the following treatment. Diffraction is the phenomena that explains the digression of a wave from a straight line path, under the influence of an obstacle, so as to propagate behind the obstacle. It is an inherent feature of a wave be it longitudinal or transverse. For e.g the sound can be heard in a room, where the source of the sound is another room without having any line of sight.

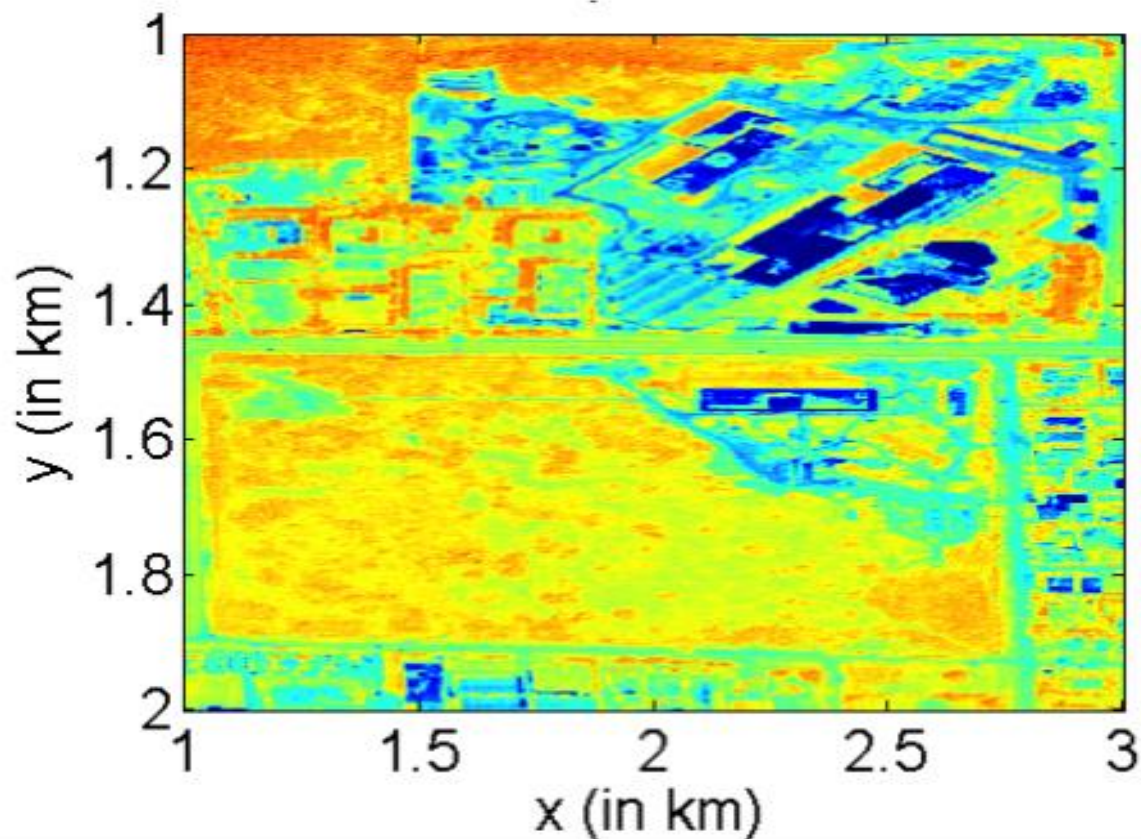


Figure 11 Simulation 5

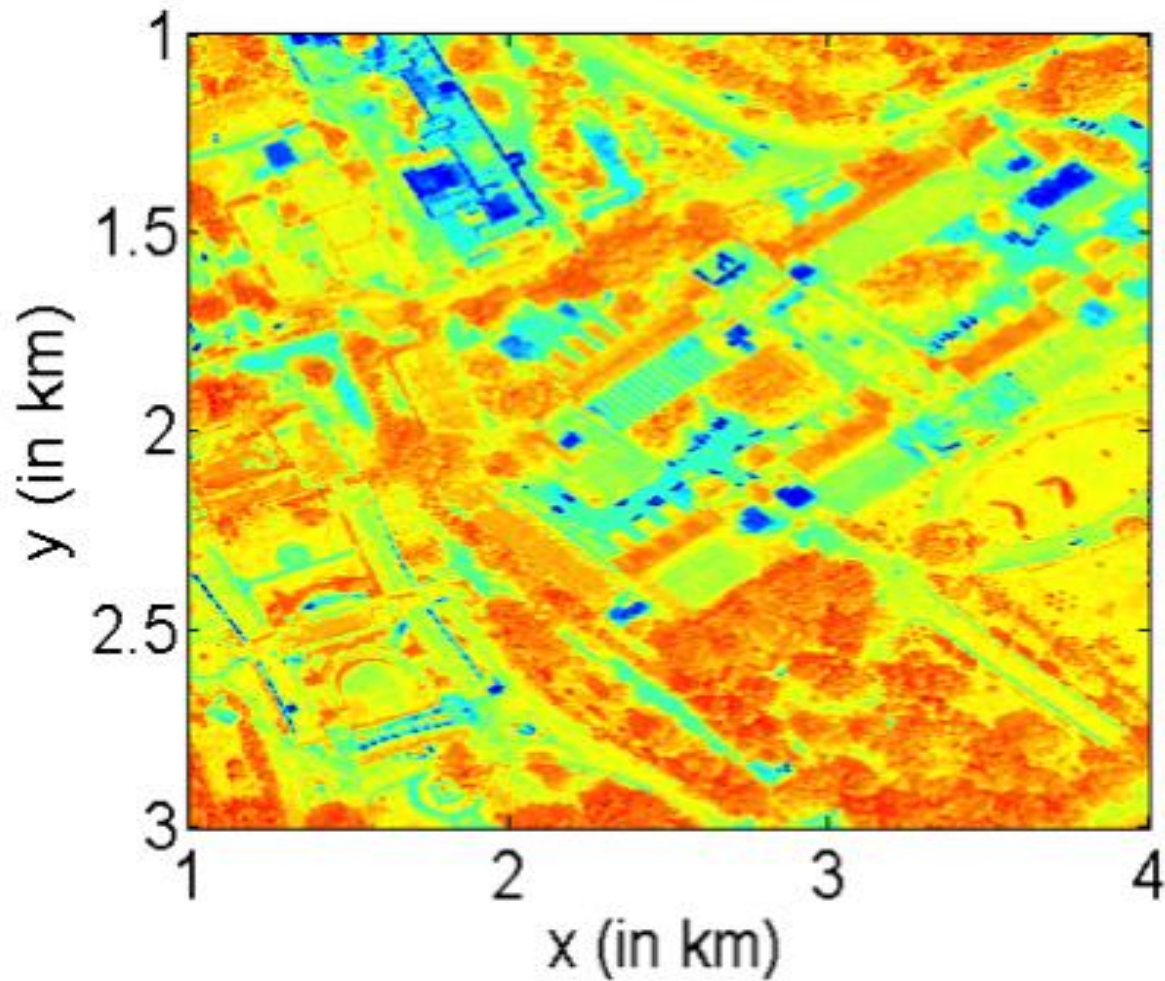


Figure 12 Simulation 6

Even though numerical prediction approximations and assumptions can be compromised with an aim to alienate some of most of their issues. Finite difference time domain (FDTD) method provides a rugged tool for the purpose. Hence this technique was adopted in this study. Additionally a measurement study on field strength of various signal sources at different frequency has also been carried out. Empirical models are based on observations and measurement alone, and are mainly used to predict the path loss. Deterministic method are governed by the principles of Electromagnetic (EM) wave propagation to predict the received signal power at a particular location.

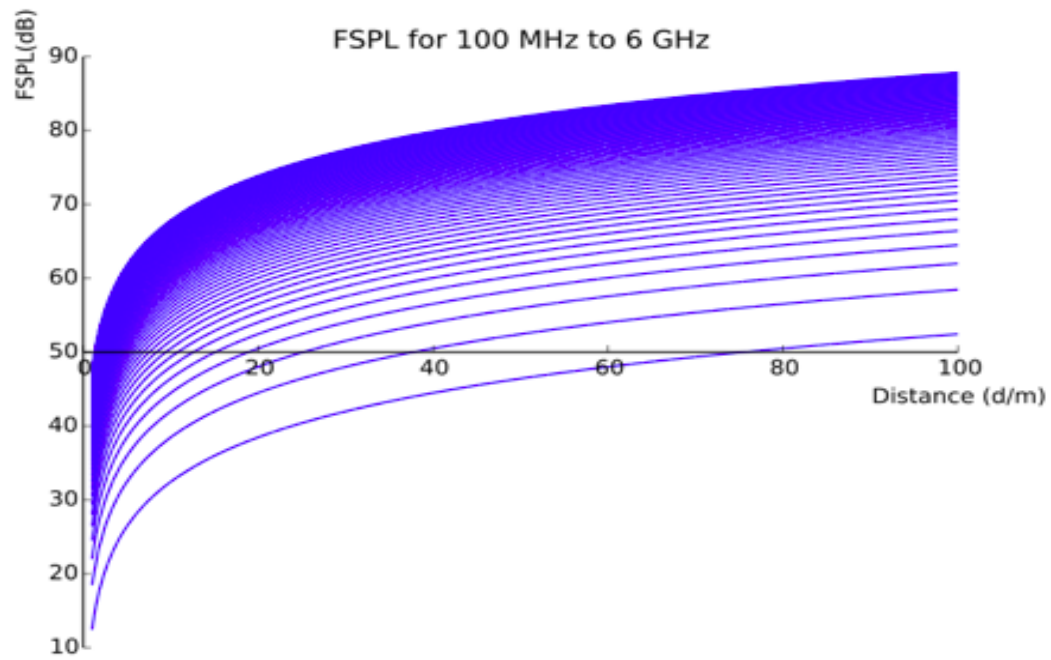


Figure 13 FPSL vs Distance (1)

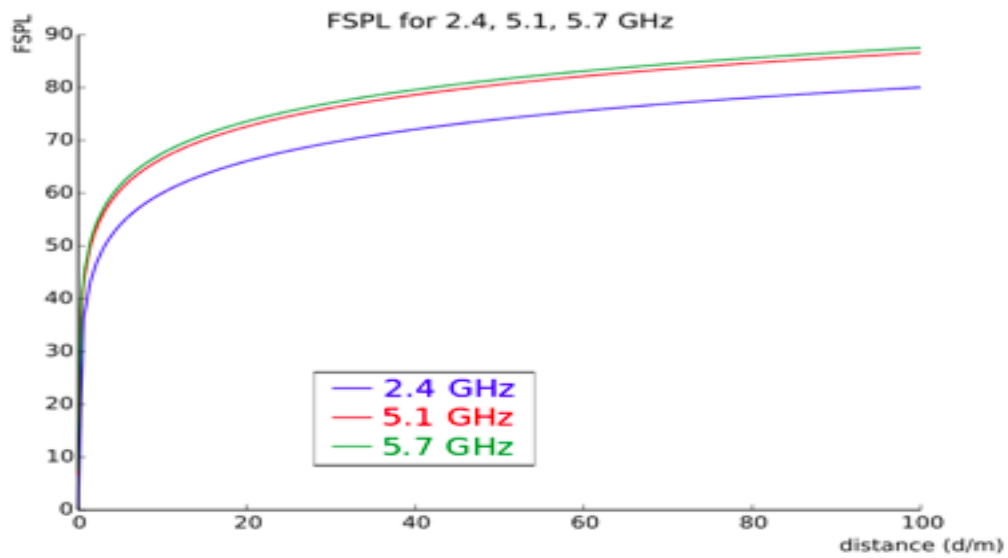


Figure 14 FPSL vs Distance (2)

Free space path loss (FSPL) is the loss in signal strength of an electromagnetic wave that would result from a line-of-sight path through free space (usually air), with no obstacles nearby to cause reflection or diffraction. Free-space path loss is proportional to the square of the distance between the transmitter and receiver, and also proportional to the square of the radio signal frequency. Free-space propagation signal power loss is proportional to the square of the distance between the transmitter and receiver, and is also also proportional to the square of the frequency of the radio signal. The inverse square law determines the spreading of electromagnetic energy in free space. Here we include the antenna gain g , which is a measure of the ability of the antenna to concentrate (direct) power in a given direction, also termed as directivity. The maximum of the value has a greater significance as it has more risk assessment characteristics. The measurement from the transmitting sources (X-Band & Telecommand) are observed. The field of radio transmission and propagation has remained a topic of interest to all RF engineers. The aim is to predict the signal strength at a particular sector. The area of interest for getting the field strength may vary a widely in complexity and accuracy. This study is based on the systematic interpretation of measured data. Radio channel may include general household area, propagation area may be a forest environment, hilly terrain and suffers from attenuation due to rain, fog, snow, moisture etc. Many propagation model have been developed that include most simple radio propagation model, the free space path loss model and the Two ray flat earth model. recent advances in computer aided tools have provided a scope for FDTD method. Predicting the RF signal level over a coverage area for radio frequency is a challenging problem. The radio channel may involve radio frequency interactions with hills, foliage, and buildings. The signal propagation path may involve different distances over hill, interaction with urban building, foliage, and urban areas. Simultaneously existing methods for making physics-based predictions of radio propagation are limited to single classes of interactions, such as urban terrain or indoor propagation model. There are many empirical outdoor propagation models such as Longley-Rice model, Durkin's model, Okumura model, Hata model etc. Longley-Rice model is the most commonly used model within a frequency band of 40 MHz to 100 GHz over different terrains. These fluctuations in power are because of extremely minute scattering processes that render to the physics based processes which cannot be accommodated in fdtd.

Sl. No.	Station Name	Operating Freq	Transmitting Power
1	BS-1	2725 MHz	450 Watt
2	BS-2	5450 MHz	600 Watt
3	BS-5	5.35 MHz	300 Watt
4	BS-6	2805,2860 MHz	1 Watt
5	BS-7	5500 MHz	1.6 Watt
6	BS-4	434 MHz	100 Watt
7	BS-3	10540 MHz	450 Watt

Based on RF measurement at different key sites, RF mapping of entire ROI has been generated and plotted. Google map of ROI has been taken as the base line geographical structure of the site and RF analysis carried using simulation techniques. Following models are generally adopted for RF radiation analysis and prediction. A simulation of a mobile fading channel has been shown below. Here we derive the signal fading as it passes through a mobile channel and also generate the doppler fading spectrum of the channel. The essential blocks used were

MOBILE FADING : Multipath signals are received in a terrestrial environment, i.e., where different forms of propagation are present and the signals arrive at the receiver from transmitter via a variety of paths. Therefore there would be multipath interference, causing multipath fading. Adding the effect of movement of either Tx or Rx or the surrounding clutter to it, the received overall signal amplitude or phase changes over a small amount of time. Mainly this causes the fading.

SPECTRUM : It is also worth noting that the mathematical Fourier transformation also accommodates the phase of the signal. However for many testing applications the phase

information is not needed and considerably complicates the measurements and test equipment. Also the information is normally not needed, and only the amplitude is important.

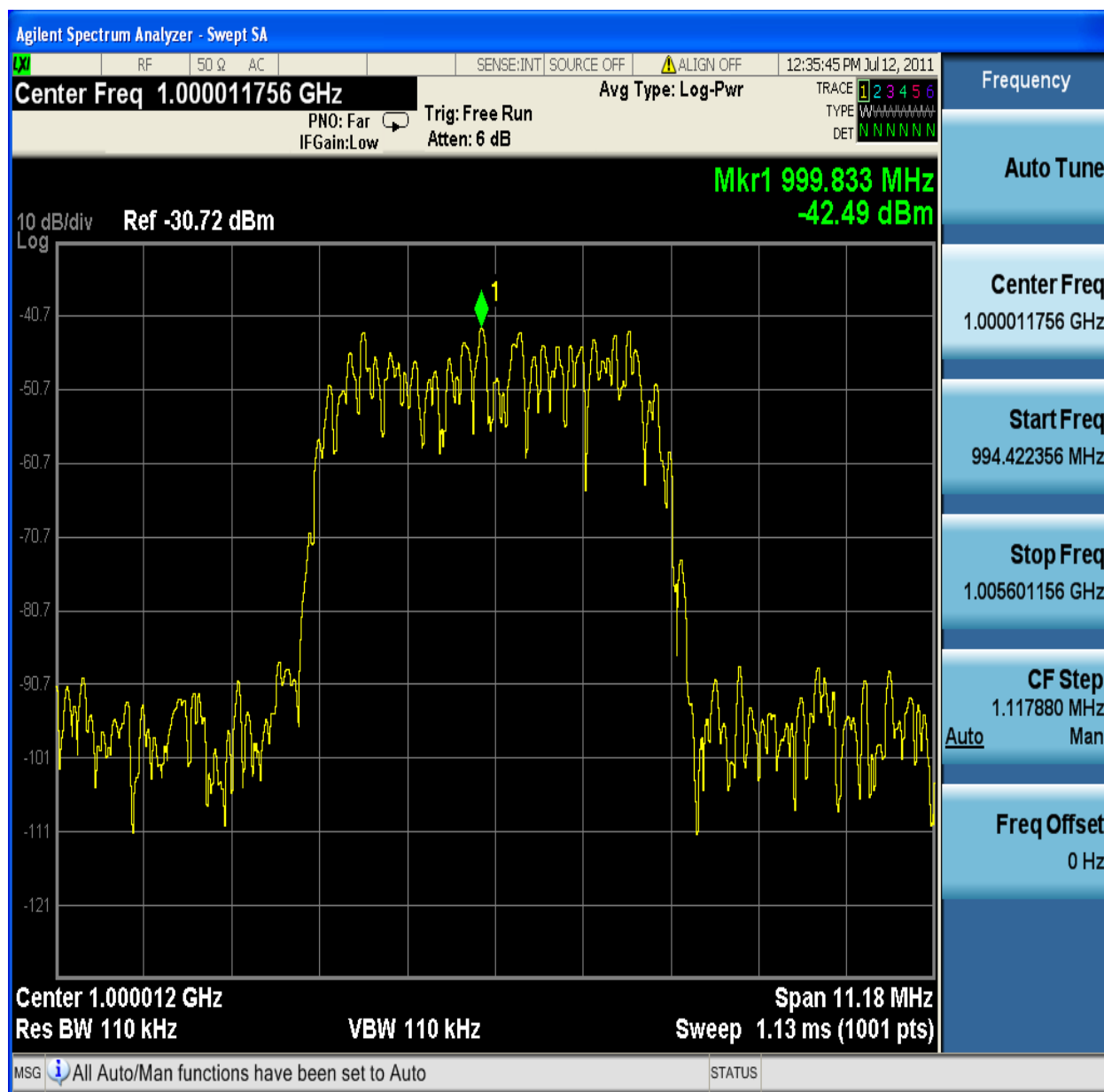


Figure 15 Spectrum Analyzer

RF Source	Operating Freq	Tx Power	Gain(dBi)	GPS Position
BS-1	2725 MHz	450 Watt	33	21.425446N 86.995167E
BS-2	5450 MHz	600 Watt	43	21.437648N 87.008162E
BS-3	10540 MHz	450 Watt	50	21.412542N 86.984525E
BS-4	434 MHz	100 Watt	0	21.439136N 86.984525E

Power level distribution over the various complexes due to individual transmitting stations has been simulated using FDTD technique. RF radiation values in different regions have been represented in colormap, with a vertical colour bar showing the mapping of the power level in the map. The color bars shows the relative power levels at various locations located in the colormap. If the value of power level is high, it is depicted by Red color.

The stated measurement have been taken at various locations using a spectrum analyzer. Maximum value of power level measure values were presented. The maximum of the value has a greater significance as it has more risk assessment characteristics. The measurement from the transmitting sources (X-Band & Telecommand) are observed at various point of time, and have been tabulated in further sections.

The measurement values of Telecommand and X-band radar has been observed at various times. The measurements are taken at launch complexes and also at LRSAM BH Top. Measurements were recorded on 9th Jun, 04 Aug and 07 Oct 2014. Only values having high power strength has been presented. The table shows the source, site of measurement, date and the signal strength. Though maximum number of transmitting stations were expected to be operated however, due to technical reasons, KAMA & PCMC were not in the on state for radiation measurement. The main aim of repeated measurement at same site was to observe any seasonal variance.

With the development of new programmable graphics hardware, novel solutions to compute electromagnetics are being already implemented on GPUs. Our implementation is formulated for 2D scenarios, being thus very suitable to perform coverage simulations in flat or near-flat urban and indoor environments. Although the memory requirements will be substantially higher, porting the traditional Yee formulae to the memory and execution scheme presented in this paper can easily derive a 3D implementation. A direct conclusion is thus that dividing the computation into several kernels for the different parts of the scenario is more suitable than having one single kernel computing the whole environment. Since the different field updates are calculated by taking derivatives on the other fields, continuity must exist in the transition from one cell to the adjacent, i.e. no cell within the scenario can be skipped from the calculation. As seen from figure 3, even the pixels that correspond to the inside of the buildings have been computed, evincing the high attenuation introduced by the walls of the buildings for indoor reception. Nevertheless, the outdoor-to-indoor power prediction in this case must be considered optimistic due to the lack of information regarding the inner structure of the different buildings. Finally, simulation results for an urban environment are presented where the extreme accuracy of FDTD for coverage prediction is evinced. Since this method is a direct approximation to the Maxwell equations, the only limit to the achievable precision is in the proper calibration and configuration of the different FDTD parameters. It has been shown that in very short running times, it is possible to perform highly accurate predictions that implicitly consider all the distortions suffered by the propagation of an electromagnetic wave. Since this is a 2D implementation, we believe that this model is specially appropriate for near-flat urban as well as indoor environments. We have introduced an efficient memory access scheme that matches the execution threads to the different cells within the Yee lattice. Furthermore, the applicability of each memory space to the implementation of an FDTD algorithm to minimize memory accesses and increase simulation speed is introduced. Besides and in order to minimize threads serialization and exploit the parallel capabilities.

Factors of Inaccuracy in FDTD:

1. Multipath propagation – Multipath is the propagation phenomenon that results in radio signals reaching the receiving antenna by two or more paths. The effects of multipath include constructive and destructive interference, and phase shifting of the signal.

2. Speed of the mobile – The relative motion between the base station and the mobile results in random frequency modulation due to different doppler shifts on each of the multipath components.
3. Speed of surrounding objects – If objects in the radio channel are in motion, they induce a time varying Doppler shift on multipath components. If the surrounding objects move at a greater rate than the mobile, then this effect dominates fading.
4. Transmission Bandwidth of the signal – If the transmitted radio signal bandwidth is greater than the “bandwidth” of the multipath channel (quantified by coherence bandwidth), the received signal will be distorted.

The rate of the change of the channel impulse response is much less than the transmitted signal. We can consider a slow faded channel a channel in which channel is almost constant over at least one symbol duration. If the transmitted signal is able to resolve the multipaths, then average small-scale receiver power is simply sum of average powers received from each multipath components. If the signal bandwidth is greater than multipath channel bandwidth then fading effects are negligible. If the signal bandwidth is less than the multipath channel bandwidth, large fading occurs due to phase shift of unresolved paths. Coherence bandwidth is a statistical measure of the range of frequencies over which the channel can be considered to pass all the frequency components with almost equal gain and linear phase. When this condition is satisfied then we say the channel to be flat. The flat and frequency selective fading create small deviations in our results and simulations corresponding to the finite difference time domain implementation. Nevertheless this method does give us a rudimentary analysis of the radio coverage hovered over an entire area. This especially gives accurate results for urban scenarios.

4.3 INDOOR PROPAGATION

The indoor radio channel differs from the traditional mobile radio channel in ways - the distances covered are much smaller ,and the variability of the environment is much greater for smaller range of Tx-Rx separation distances. Features such as lay-out of the building, the construction materials, and the building type strongly influence the propagation within the building. Indoor radio propagation is dominated by the same mechanisms as outdoor: reflection, diffraction and

scattering with variable conditions. In general, indoor channels may be classified as either line-of-sight or obstructed. A channel model is useful in determining the mechanisms by which propagation in the indoor environment occurs, which in turn is useful in the development of a communication system. By examining the details of how a signal is propagated from the transmitter to the receiver for a number of experimental locations, a generic model may be developed that highlights the important characteristics of a given indoor environment. Generic models of indoor communications can then be applied to specific situations to describe the operation of a radio system, and may also be used to generate designs that are particularly suited to supporting radio communication systems.

4.3.1 INTRA-FLOOR

The internal and external structure of a building formed by partitions and obstacles vary widely. Partitions that are formed as a part of building structure are called hard partitions, and partitions that may be moved and which do not span to the ceiling are called soft partitions. Partitions vary widely in their physical and electrical characteristics, making it difficult to apply general models to specific indoor installations. Regarding path-loss, one important factor introduced in this chapter is log-distance path loss model. These, however, may be insignificant when we consider the small-scale rapid path losses. The ray-tracing approach approximates the scattering of electromagnetic waves by simple reflection and refraction. The degree of transmission and reflection of a signal through and off an obstacle is related to the complex permittivities of the obstacle. One of the propagation models based on ray-optic theory is the Two-Ray model.

4.3.2 INTER-FLOOR

The external dimensions and materials of the building, as well as the type of construction used to create the floors and the external surroundings determine the losses between floors of a building. Even the number of windows in a building and the presence of tinting can impact the loss between floors. It has been observed that indoor path loss obeys the distance power law given by

$$PL(\text{dB}) = PL(d_0) + 10n \log_{10}(d/d_0) + X_{\sigma} \quad (4.73)$$

where n depends on the building and surrounding type, and X_{σ} represents a normal random variable in dB having standard deviation of σ dB. Random shadowing effects occurring over a large number of measurement locations, which have the same T-R separation, but different levels of clutter on the propagation path, is referred to as Log-Normal Distribution. When an analyst attempts to fit a statistical model to observed data, they may wonder how well the model actually reflects the data. How “close” are the observed values to those which would be expected under the fitted model? One statistical test that addresses this issue is the chi-square goodness-of-fit test. Field data is often accompanied by noise. Even though all control parameters (independent variables) remain constant, the resultant outcomes (dependent variables) vary. A process of quantitatively estimating the trend of the outcomes, also known as regression or curve fitting, therefore becomes necessary.

CHAPTER 5

CONCLUSION HEALTH EFFECTS

5 HEALTH EFFECTS

Radio waves and microwaves are forms of electromagnetic energy that are collectively described by the term "radiofrequency" or "RF." RF emissions and associated phenomena can be discussed in terms of "energy," "radiation" or "fields." Radiation is defined as the propagation of energy through space in the form of waves or particles. Electromagnetic "radiation" can best be described as waves of electric and magnetic energy moving together (i.e., radiating) through space as illustrated . These waves are generated by the movement of electrical charges such as in a conductive metal object or antenna.

Since the speed of light in a given medium or vacuum does not change, highfrequency electromagnetic waves have short wavelengths and low-frequency waves have long wavelengths. The electromagnetic "spectrum" includes all the various forms of electromagnetic energy from extremely low frequency (ELF) energy, with very long wavelengths, to X-rays and gamma rays, which have very high frequencies and correspondingly short wavelengths.

The most important are:

1. The higher the radiation dose, the greater the chance of developing cancer.
2. The chance of developing cancer, not the seriousness of the cancer, increases as the radiation dose increases.
3. Cancers caused by radiation do not appear until years after the radiation exposure.
4. Some people are more likely to develop cancer from radiation exposure than others.
5. Higher levels can lead to destruction of living tissue.
6. Frequency and Intensity varies from places to places and from people to people.

Microwaves are a specific category of radio waves that can be defined as radiofrequency radiation where frequencies range upward from several hundred megahertz (MHz) to several gigahertz (GHz). One of the most familiar and widespread uses of microwave energy is found in household microwave ovens, which operate at a frequency of 2450 MHz (2.45 GHz).

Radiofrequency radiation, especially at microwave frequencies, efficiently transfers energy to water molecules. At high microwave intensities the resulting energetic water molecules can generate heat in water-rich materials such as most foods. The operation of microwave ovens is based on this principle. This efficient absorption of microwave energy via water molecules results in rapid heating throughout an object, thus allowing food to be cooked more quickly than in a conventional oven.

Photons associated with X-rays and gamma rays (which have very high electromagnetic frequencies) have a relatively large energy content. At the other end of the electromagnetic spectrum, photons associated with low-frequency waves (such as those at ELF frequencies) have many times less energy. In between these extremes ultraviolet radiation, visible light, infrared radiation, and RF energy (including microwaves) exhibit intermediate photon energy content. For comparison, the photon energies associated with high-energy X-rays are billions of times more energetic than the energy of a 1-GHz microwave photon.

Because an RF electromagnetic field has both an electric and a magnetic component (electric field and magnetic field), it is often convenient to express the intensity of the RF field in terms of units specific for each component. The unit "volts per meter" (V/m) is often used to measure the strength ("field strength") of the electric field, and the unit "amperes per meter" (A/m) is often used to express the strength of the magnetic field.

Power density is defined as power per unit area. For example, power density can be expressed in terms of milliwatts per square centimeter (mW/cm^2) or microwatts per square centimeter ($\mu\text{W}/\text{cm}^2$). One mW equals 0.001 watt of power, and one μW equals 0.000001 watt. With respect to frequencies in the microwave range and higher, power density is usually used to express intensity since exposures that might occur would likely be in the far field. A biological

effect occurs when a change can be measured in a biological system after the introduction of some type of stimuli. However, the observation of a biological effect, in and of itself, does not necessarily suggest the existence of a biological hazard. A biological effect only becomes a safety hazard when it "causes detectable impairment of the health of the individual or of his or her offspring". Two areas of the body, the eyes and the testes, are known to be particularly vulnerable to heating by RF energy because of the relative lack of available blood flow to dissipate the excessive heat load (blood circulation is one of the body's major mechanisms for coping with excessive heat). Laboratory experiments have shown that short-term exposure (e.g., 30 minutes to one hour) to very high levels of RF radiation (100-200 mW/cm²) can cause cataracts in rabbits. Temporary sterility, caused by such effects as changes in sperm count and in sperm motility, is possible after exposure of the testes to high-level RF radiation (or to other forms of energy that produce comparable increases in temperature). In addition to intensity, the frequency of an RF electromagnetic wave can be important in determining how much energy is absorbed and, therefore, the potential for harm. The quantity used to characterize this absorption is called the "specific absorption rate" or "SAR," and it is usually expressed in units of watts per kilogram (W/kg) or milliwatts per gram (mW/g). In the far-field of a source of RF energy (e.g., several wavelengths distance from the source) whole-body absorption of RF energy by a standing human adult has been shown to occur at a maximum rate when the frequency of the RF radiation is between about 80 and 100 MHz, depending on the size, shape and height of the individual. In other words, the SAR is at a maximum under these conditions. Because of this "resonance" phenomenon, RF safety standards have taken account of the frequency dependence of whole-body human absorption, and the most restrictive limits on exposure are found in this frequency range (the very high frequency or "VHF" frequency range). As a result of this the exceeding limit of radio wave power can have far reaching consequences on human health and living tissue in general. However it must be kept in mind that the relations of human health and radiation level varies from person to person.

Not all standards and guidelines throughout the world have recommended the same limits for exposure. For example, some published exposure limits in Russia and some eastern European countries have been generally more restrictive than existing or proposed recommendations for exposure developed in North America and other parts of Europe. This discrepancy may be due, at least in part, to the possibility that these standards were based on exposure levels where it was believed no biological effects of any type would occur. This philosophy is inconsistent with the approach taken by most other standards-setting bodies which base limits on levels where recognized hazards may occur and then incorporate appropriate safety margins to ensure adequate protection. In the United States, although the Federal Government has never itself developed RF exposure standards, the FCC has adopted and used recognized safety guidelines for evaluating RF environmental exposure since 1985. Federal health and safety agencies, such as the Environmental Protection Agency (EPA), the Food and Drug Administration (FDA), the National Institute for Occupational Safety and Health (NIOSH) and the Occupational Safety and Health Administration (OSHA) have also been actively involved in monitoring and investigating issues related to RF exposure. For example, the FDA has issued guidelines for safe RF emission levels from microwave ovens, and it continues to monitor exposure issues related to the use of certain RF devices such as cellular telephones. NIOSH conducts investigations and health hazard assessments related to occupational RF exposure. In 1971, a federal RF radiation protection guide for workers was issued by OSHA based on the 1966 American National Standards Institute (ANSI) RF exposure standard. However, the OSHA regulation was later ruled to be advisory only and not enforceable. Presently, OSHA enforcement actions related to RF exposure of workers are undertaken using OSHA's "general duty clause," which relies on the use of widely-supported voluntary "consensus" standards such as those discussed below. In 1986, the NCRP issued exposure criteria for the workplace that were the same as the 1982 ANSI recommended levels, but the NCRP also recommended more restrictive limits for exposure of the general public. Therefore, the NCRP exposure criteria included two tiers of recommended limits, one for the general population and another for occupational exposure. In 1987, the ANSI committee on RF exposure standards (Standards Coordinating Committee 28) became a committee of the IEEE, and, in 1991, revised its earlier standard and issued its own two-tiered standard that had been developed over a period of several years.

We now present the measured radiation levels in our simulation. We measure the values at four hypothetical regions, reg1, reg2, reg3, reg4.

RF Source	Observe point	Distance (Km)	E (v/m)	H (A/m)	R _X Power (dBm)
BS-1	reg1	2.762	6.861	0.00085	-18.107
BS-1	reg2	3.521	1.114	0.00295	-21.171
BS-1	reg3	10.56	1.795	0.00085	-27.025
BS-1	reg4	1.812	0.5729	0.00087	-26.942

Power and Field Strength due to PCMC radar.

RF Source	Observe point	Distance (Km)	E(v/m)	H(A/m)	R _X Power (dBm)
BS-2	reg1	0.957	32.37	0.08585	-7.45
BS-2	reg2	1.671	18.54	0.04918	-12.296
BS-2	reg3	6.849	4.524	0.01200	-24.549
BS-2	reg4	6.750	4.590	0.01218	-24.43

Power and Field Strength of X-band

RF Source	Observe point	Distance (Km)	E(v/m)	H(A/m)	R _X Power (dBm)
BS-3	reg1	0.8827	5.880	0.01560	-10.539
BS-3	reg2	3.476	1.385	0.00396	-22.44
BS-3	reg3	8.654	0.5997	0.00159	-30.367
BS-3	reg4	8.558	0.6064	0.00161	-30.270

Power and Field Strength of KAMA

RF Source	Observe point	Distance (Km)	E(v/m)	H(A/m)	R _X Power (dBm)
BS-4	reg1	2.940	0.01863	0.007799	-46.565
BS-4	reg2	5.654	0.00984	0.00002	-52.105
BS-4	reg3	10.74	0.00510	0.000013	-57.818
BS-4	reg4	10.65	0.00514	0.000013	-57.745

Power and Field Strength of T-Command

The ANSI/IEEE standards have been widely used and cited and have served as the basis for similar standards in the United States and in other countries. Both the NCRP and ANSI/IEEE guidelines were developed by scientists and engineers with a great deal of experience and knowledge in the area of RF biological effects and related issues. These individuals spent a considerable amount of time evaluating published scientific studies relevant to establishing safe levels for human exposure to RF energy. In addition to NCRP and ANSI/IEEE, other organizations and countries have issued exposure guidelines. For example, several European countries are basing guidelines on exposure criteria developed by the International Committee on Nonionizing Radiation Protection (ICNIRP). The ICNIRP guidelines are also derived from an SAR threshold of 4 W/kg (for adverse effects) and are similar to the 1992 ANSI/IEEE and NCRP recommendations with certain exceptions. For example, ICNIRP recommends somewhat different exposure levels in the lower and upper frequency ranges and for localized exposure due to such devices as hand-held cellular telephones. Many, but not all, countries have based exposure recommendations on the same general concepts and thresholds as those used by the NCRP, ANSI/IEEE and ICNIRP. Because of differences in international standards, the World Health Organization (WHO), as part of its EMF Project (discussed earlier), has initiated a program to try and develop an international framework for RF safety standards.

In 1985, the FCC adopted the 1982 ANSI guidelines for purposes of evaluating exposure due to RF transmitters licensed and authorized by the FCC. This decision was in response to provisions of the National Environmental Policy Act of 1969 requiring all Federal Government agencies to evaluate the impact of their actions on the "quality of the human environment."⁵ In 1992, ANSI adopted the 1991 IEEE standard as an American National Standard (a revision of its 1982 standard) and designated it ANSI/IEEE C95.1-1992.

The FCC considered a large number of comments submitted by industry, government agencies and the public. In particular, the FCC considered comments submitted by the EPA, FDA, NIOSH and OSHA, which have primary responsibility for health and safety in the Federal Government. The guidelines the FCC adopted were based on the recommendations of those agencies

From the simulated results, we can find the percentage of the areas that come under extremely high exposure. This gives us an idea about the fraction of area in the ROI under high radio power.

Region	% area under high exposure(> 12dB)	% area under medium exposure(<12dB and >-40dB)	% area under low exposure(<-40dB)
Civil Township, Rourkela	8.9%	68.2%	22.9%
Udit Nagar, Rourkela	5.7%	75.17%	19.13%
Koel Nagar, Rourkela	7.3%	71.7%	21%
Bus Stand, Cuttack	17.4%	51.31%	31.29%
Rural Rea 1	12.1%	50.2%	37.7%
Rural Area 2	13.2%	68.6%	18.2%

It can be seen from the data that, places with lesser obstacles tend to have a higher radiation level. This is an expected result because obstacles reduce the radio power by different physical phenomena such as reflection, absorption, diffraction, scattering etc. Hence regions with higher number of buildings tend to have a lower radio coverage.

Most radiofrequency safety limits are defined in terms of the electric and magnetic field strengths as well as in terms of power density. For lower frequencies, limits are more meaningfully expressed in terms of electric and magnetic field strength values, and the indicated power densities are actually "far-field equivalent" power density values. The latter are listed for comparison purposes and because some instrumentation used for measuring RF fields is calibrated in terms of far-field or plane-wave equivalent power density. At higher frequencies, and when one is actually in the "far field" of a radiation source, it is

usually only necessary to evaluate power density. In the far field of an RF transmitter power density and field strength are related by standard mathematical equations.

The time-averaging concept can be illustrated as follows for exposure in a workplace environment. The sum of the product (or products) of the actual exposure level(s) multiplied by the actual time(s) of exposure must not be greater than the allowed (average) exposure limit times the specified averaging time. Therefore, for 100 MHz would be permitted for three minutes in any six-minute period as long as during the remaining three minutes of the six-minute period the exposure was at or near "zero" level of exposure.

The lower part of the frequency spectrum is considered non-ionizing Electromagnetic Radiation (EMR), with energy levels below that required for effects at the atomic level. Examples of non-ionizing radiations are:

- Static electromagnetic fields from direct current (0 Hz)
- Low-frequency waves from electric power (50-60 Hz)
- Extremely Low Frequency (ELF) and Very Low Frequency (VLF) fields (up to 30 kHz)
- Radio Frequencies (RF), including Low Frequency (LF), Medium Frequency (MF) High Frequency (HF), Very High Frequency (VHF), Ultra High Frequency (UHF) and Microwave (MW) and Millimeterwave (30 kHz to 300 GHz)
- Infrared (IR) light, Visible light and Ultraviolet (UV) light (above 300 GHz)

Some heating effect is generated by all of these waves. Insufficient energy is available from most common sources to produce any type of damage to human tissue, although it is probable that higher power densities, such as those densities very near high-voltage power lines or high-power (megawatt) broadcast transmitters, could have long-term health effects. The power density of any source of EMR is not only related to the power level at the source, but increases rapidly as the

distance from the source decreases. A common concern today, since more and more people are using cell phones than ever before, is that cell phone antennas radiate near a person's head. Cell phones, however, radiate very little power. So, even while close to the head, they are not considered a danger. Some studies suggest that potential health hazards could be linked to excessive exposure to high-power densities of non-ionizing radiation. These health hazards include:

- Cancer
 - Tumors
 - Headaches
 - Fatigue
 - Alzheimer's Disease
 - Parkinson's Disease
- Researchers, however, are unsure of specific long-term effects resulting from prolonged exposure to non-ionizing radiation.

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